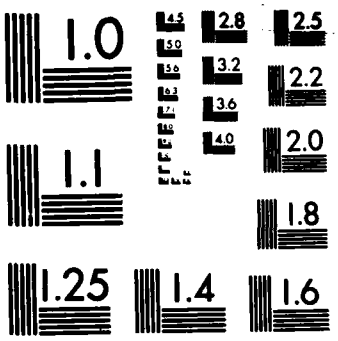
AD-A174 787 RESEARCH ON OPTIMIZATION-BASED COMPUTER-AIDED DESIGN OF CONTROL SYSTEMS(U) CALIFORNIA UNIV BERKELEY ELECTRONICS RESEARCH LAB E POLAK 05 DEC 86 N00014-83-K-0602 1/1

UNCLASSIFIED F/G 9/2 NL



(12)

AD-A174 787

RESEARCH ON OPTIMIZATION-BASED COMPUTER-AIDED DESIGN OF CONTROL SYSTEMS

FINAL REPORT

by

Elijah Polak

for

Office of Naval Research

Contract N00014-83-K-0602

August 1, 1983 to July 31, 1986

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

ADA 174 787

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) N00014-83-K-0602
6a. NAME OF PERFORMING ORGANIZATION Electronics Research Lab. — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Office of Naval Research
6c. ADDRESS (City, State, and ZIP Code) University of California Berkeley, CA 94720	7b. ADDRESS (City, State, and ZIP Code) 800 N. Quincy Street Arlington, VA 22217
8a. NAME OF FUNDING / SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. — PROJECT NO. — TASK NO. — WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

RESEARCH ON OPTIMIZATION-BASED COMPUTER-AIDED DESIGN OF CONTROL SYSTEMS

12. PERSONAL AUTHOR(S)
Elijah Polak

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 8/1/83 TO 7/31/86	December 5, 1986	9

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	nondifferentiable optimization, semi-infinite optimization computer-aided design, control system design

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The research covered by this report was aimed at advancing the state of the art of optimization-based design of control systems. To this end, research was carried out in three areas: (i) the development of a theory of nondifferentiable optimization algorithms for the solution problems with max type inequality constraints, (ii) the exploration of efficient design parametrization and initialization techniques in optimization-based control system design, and finally, (iii) the development of interactive software for optimization-based control system design.

As a result of this research, two students will receive their Ph.D. degrees in November, 1986, two students are are halfway through their doctoral research projects, and our interactive optimization-based design system DELIGHT.MIMO was completed. It is currently being installed in alpha sites for testing and evaluation. The Michelson Laboratory in China Lake is one such test site.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. Robin Simpson	22b. TELEPHONE (Include Area Code) — 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

The research covered by this report was aimed at advancing the state of the art of optimization-based design of control systems. To this end, research was carried out in three areas: (i) the development of a theory of nondifferentiable optimization algorithms for the solution problems with max type inequality constraints, (ii) the exploration of efficient design parametrization and initialization techniques in optimization-based control system design, and finally, (iii) the development of interactive software for optimization-based control system design.

(i) Since 1984, we have been working on a constructive theory of nondifferentiable optimization algorithms. The purpose of this theory is to elucidate the principles of nondifferentiable optimization algorithm construction. A first version of this theory appeared in [2], it was further refined in [3] and it will appear in final form in SIAM Review in February 1987. The SIAM Review is probably the only publication where one can publish a paper dealing with a new and complex theory in an expository fashion. Our manuscript is well over 100 pages long and, hopefully, sufficiently self contained to open up our algorithms and algorithm construction tools to a wide audience. The most important aspects of our work are: (a) the discovery of a mechanism for generating continuous search direction functions which lead to extremely well behaved optimization algorithms, and (b) the discovery that the generation of nondifferentiable optimization algorithms is "elastic" in the sense that one can generate endless families of nondifferentiable optimization algorithms. There are two important consequences to this elasticity, the first is that it has enabled us to construct new, quadratically convergent algorithms for semi-infinite optimization (manuscript in preparation) and the second is that it opened up new avenues for scaling algorithms so as to

enhance their behavior. The exploration of the latter has become the topic of a doctoral dissertation.

(ii) Our work on efficient parametrizations techniques for use in optimization-based control system design was reported in [1] and [4] to [15].

In [1, 12, 14] we presented our work on worst case design in the presence of structured and unstructured uncertainty. Our major contribution in this area is a computational complexity reduction scheme.

In [6] and [7] we showed that it is possible to define an uncertainty identification scheme which can be used to produce information for redesigning the control system under worst case assumptions. We showed that this new approach to adapative control results in a stable system whose performance improves with time, as the system uncertainty is reduced.

In [15] and a follow up paper, in preparation, we show that the well known, so called Zames' Q-parametrization of stabilizing compensators leads to transcriptions of control system design problems with both time *frequency domain and time domain* constraints, specified in terms of bounds on H_∞ norms on transfer function matrices (in frequency domain) or impulse response matrices (in time domain) into convex, semi-infinite optimization problems. The effect of Q-parametrization induced convexity is to remove the undesirable effects of local minima which result from other types of parametrizations. We showed that these constrained H_∞ problems can be solved by our new semi-infinite optimization algorithms and presented numerical results for a couple of sample problems. Thus our algorithms considerably advance the possibilities of

design using H_∞ concepts, as well as control system design with respect to other norms. We are currently exploring techniques for extending these results for the design of *finite dimensional* stabilizing controllers for large, flexible structures.

Our research on optimal control algorithms, which can be used for solving optimal control problems with either ODE or PDE type dynamics, control and state space constraints, was presented in [11]. Finally, our work on control system design formulation as a semi-infinite optimization problem and on simulation techniques for optimization-based control system design were presented in [4, 5, 8, 13]. Finally, [9, 10] present some preliminary results on algorithms dealing with collision avoidance problems.

(iii) Our interactive, optimization-based computer-aided multivariable control system design package, DELIGHT.MIMO, has recently been completed and is being placed in alpha sites for testing and evaluation. These include the Michelson Laboratory, the General Electric Co. Research Center in Schenectady, the Hewlett Packard Co. and several university sites. Hopefully, it will simplify considerably the use in industry of optimization-based computer-aided control system design tools. An important aspect of this package is a very friendly graphical user interface which makes the definition of system interconnections and transcription of a design problem into an optimization problem a simple, error free task. In addition, by powerful windowing techniques, it allows the user to examine simultaneously various systems outputs as well as their variations produced by user dictated design parameter changes.

REFERENCES

[1] E. Polak and D.M. Stimler, "On the design of linear control systems with plant uncertainty via nondifferentiable optimization", Proceedings of *The IX-th Triennial IFAC World Congress,* Budapest, July 2-6, 1984.

[2] E. Polak, "Notes on the Mathematical Foundations of Nondifferentiable Optimization in Engineering Design", University of California, Electronics Research Laboratory, Memo UCB/ERL M84/15, 2 Feb. 1984.

[3] E. Polak, "On the Mathematical Foundations of Nondifferentiable Optimization in Engineering Design", University of California, Electronics Research Laboratory, Memo UCB/ERL M85/17, 28 Feb. 1985.

[4] E. Polak, "A Perspective on the Use of Semi-Infinite Optimization in Control System Design", *1984 Automatic Control Conference,* San Diego, June 1984.

[5] E. Polak, D. Q. Mayne and D. M. Stimler, "Control System Design via Semi-Infinite Optimization", *Proceedings of the IEEE,* Vol. 72, No. 12, pp 1777-1794, December 1984.

[6] E. Polak, S. Salcudean and D. Q. Mayne, " A Rationale for the Sequential Optimal Redesign of Control Systems", Proc. *1985 ISCAS,* Kyoto, Japan, June 1985.

[7] E. Polak, S. Salcudean and D. Q. Mayne, " A sequential optimal redesign procedure for linear feedback systems", University of California, Electronics Research laboratory Memo No. UCB/ERL M85/15, Feb.28, 1985, IEEE Trans. on Automatic Control, in press.

[8] E. Polak and T. E. Baker, "A Review of Alternatives in Optimal Control Algorithms", Invited Paper, *SIAM Spring Meeting*, June 24-25 1985, Pittsburgh, Pa.

[9] D. Q. Mayne and E. Polak "Algorithms for Optimization Problems with Exclusion Constraints", Proc. 1985 IEEE Conf. on Dec. and Contr., Fort Lauderdale, Florida, Dec. 1985.

[10] D. Q. Mayne and E. Polak "Algorithms for Optimization Problems with Exclusion Constraints", University of California, Electronics Research laboratory Memo No. UCB/ERL M85/33, April 26, 1985.

[11] D. Q. Mayne and E. Polak "An exact penalty function algorithm for control problems with state and control constraints", University of California, Electronics Research laboratory Memo No. UCB/ERL M85/52, June 21 , 1985. Also, *IEEE Trans. on Automatic Control*, in press.

[12] E. Polak and D. M. Stimler, "On the efficient formulation of the optimal worst case control system design problem", University of California, Electronics Research laboratory Memo No. UCB/ERL M85/71, 21 August 1985.

[13] T. L. Wuu, R. G. Becker and E. Polak, "A diagonalization technique for the computation of sensitivity functions of linear time invariant systems", University of California, Electronics Research laboratory Memo No. UCB/ERL M86/13, 14 February 1986. Also, *IEEE Trans. on Automatic Control*, in press.

[14] E. Polak and D. M. Stimler "Majorization: a computational complexity reduction technique in control system design". *Proceedings of the* Seventh International Conference Analysis and Optimization of Systems, Nice, France, June, 1986.

[15] E. Polak and S. Salcudean, "Feedback controller design for linear multivariable plants using constrained optimization in H-infinity spaces," Presented at *6th IFAC Workshop on Control Applications of Nonlinear Programming and Optimization*, Imperial College, London, July 6-8, 1986.

[16] E. Polak, "A perspective on control system design by means of semi-infinite optimization algorithms", *Proc. IFIP Working Conference on Optimization Techniques*, Santiago, Chile, Aug. 1984. Springer Verlag, in press.

PERSONNEL

Baker, Theodore	Research Assistant
Harn, Y. W.	Research Assistant
Higgins, Joseph	Research Assistant
Nye, William	Post-Doc
Salcudean, Septimiu	Ph.D - November 1986
Vu, Loc	Ph.D - May 1986
Wang, D.	M.S. - November 1984
Wuu, Tzyh-L.	Ph.D - November 1986
Yang, T.	Research Assistant

END

1-87

DTIC